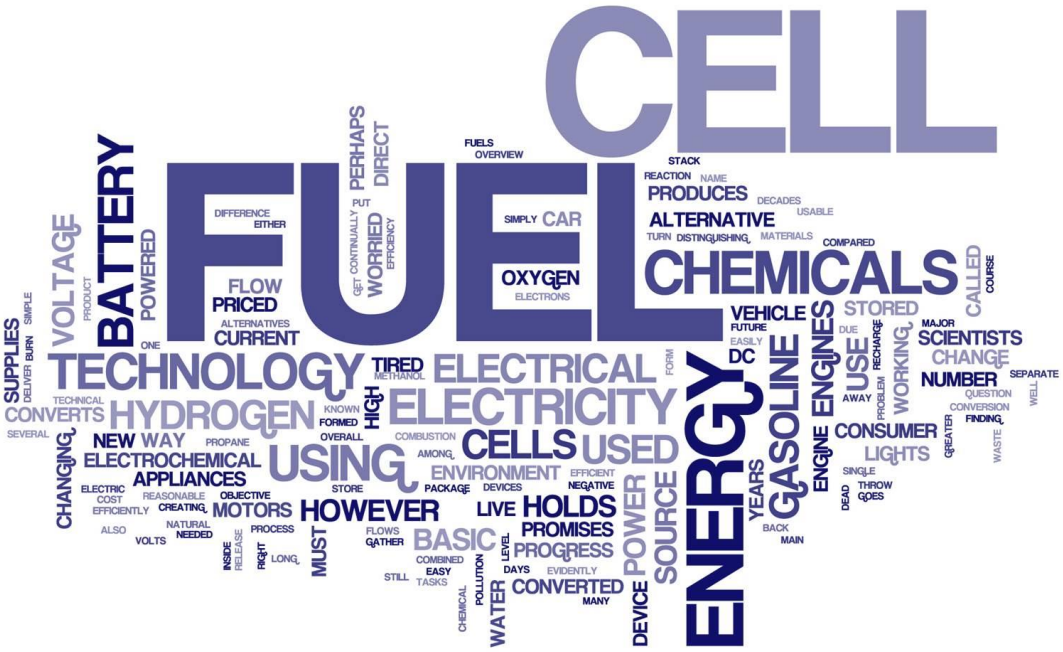
European Commission

Keyword Analysis and Project Classification of FCH 2 JU Projects

An overview of the methodology plus selected data

Davies, J.C.

2020



EUR 30187 EN

Contact information
Name: Jonathan Davies
Email: jonathan.davies@ec.europa.eu

EU Science Hub
https://ec.europa.eu/jrc

JRC119839

EUR 30187 EN

PDF ISBN 978-92-76-17296-3 ISSN 1831-9424 doi:10.2760/527632

Luxembourg: Publications Office of the European Union, 2020

How to cite this report: Davies, J.C., *Keyword Analysis and Project Classification of FCH 2 JU Projects*, EUR 30187 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17296-3, doi:10.2760/527632, JRC119839.

Contents

Acknowledgements

The author would like to thank Eleni Zafeiratou, Dimitra Dirmiki and Mirela Atanasiu of the Fuel Cell and Hydrogen Joint Undertaking 2 for helpful discussions and feedback on this study.

The author would also like to thank Eveline Weidner and Marc Steen of the Joint Research Centre of the European Commission for reviewing the manuscript.

Author

Jonathan Davies

Abstract

The Fuel Cells and Hydrogen Joint Undertaking has funded more than 240 projects since its inception in 2008, with the goal of accelerating fuel cell and hydrogen technologies to the marketplace to assist the transition to a carbon-clean energy system [1].

Priorities regarding the suitable areas for research, development and demonstration projects are under constant review. These priorities are regularly updated in the Multi-Annual Work Plan (MAWP) and Annual Work Plans (AWP).

When establishing the calls for proposals, funding is earmarked for key priorities and research areas (the highest level of classification being Energy and/or Transport). The main motivation of the current exercise was to determine relationships between funding and the various activities of the Joint Undertaking, for example to visualise trends in the funding for particular technologies or applications. As a pre-cursor to a wider historical analysis of the impact of the FCH 2 JU, a structured classification of projects according to keywords has been performed, leading to the creation of a hierarchical database. All projects up to and including the 2018 call have been included in this exercise, excluding two additional projects under preparation by FCH JU, which were not signed in time for inclusion in this report.

To achieve these goals, keywords were determined for all projects and then distributed within a hierarchical database created in Excel. Keywords were analysed based on Project Topic (encompassing the technology type and application) and Project Class (encompassing the stage and scale of the project undertaken). Finally, a series of plots were created, demonstrating how the database could be used to investigate the trends in funding at different levels of the database hierarchy.

1 Introduction

The Fuel Cell and Hydrogen Joint Undertaking (FCH JU) was established according to a European Council Regulation of 30th May 2008 as a public/private partnership between the European Commission, European Industry and Research Organisations [1]. It was renewed under the Horizon 2020 Program as the Fuel Cell and Hydrogen Joint Undertaking 2 (FCH 2 JU), as it is currently known. Its purpose is to accelerate the development and deployment of fuel cell and hydrogen technologies. To this end, it has distributed EU funds for projects related to fuel cells and hydrogen, first under Framework Program 7 (FP7) from 2008-2013 and under the Horizon 2020 Program (H2020) from 2014 onwards.

To date, more than 240 projects have been funded, with the goal of accelerating fuel cell and hydrogen technologies to the marketplace, hereby assisting in the transition to a carbon-clean energy system. Priorities regarding suitable areas for research and development are under constant review and the methods by which projects have been classified have changed over time, in particular with the transition from FP7 to Horizon 2020.

As a pre-cursor to a wider historical analysis of the impact of FCH 2 JU, a structured classification of projects according to keywords has been performed, leading to the creation of a hierarchical database. All 244 projects funded up to and including the 2018 call have been included in this exercise, excluding two additional projects under preparation by FCH JU, which were not signed in time for inclusion in this report.

The main motivation for this activity has been to show how the FCH 2 JU has distributed its funding over time, for example to visualise trends in the funding for particular technologies or applications. The output of the study should reflect the evolution of the programme, for example when a particular issue is resolved or when new challenges are identified.

Funding from the FCH 2 JU is distributed according to two main pillars, as identified in the Multi-Annual Work-Plan (MAWP) [2]: Energy and Transport. In addition, there are cross-cutting activities which are broad and perform general activities relevant to both main pillars (for example educational or safety-related work). Additionally, there are projects which are deemed "over-arching" which are Research and/or Demonstration Projects but which receive part of their funding from each pillar.

Each year the FCH 2 JU holds Programme Review Days (PRD) where an assessment of the project portfolio against key objectives of the programme is performed. The projects are split across six panels which look at specific areas of Fuel Cell and Hydrogen (FCH) development.

The Pillars and Panels are defined in Table 1. These are the panel names and topics as defined for PRD 2018. It should be noted that the panel names and definitions have changed slightly over the history of the FCH 2 JU, however the projects contained within each Panel have largely remained the same, with a few exceptions that will be noted where relevant throughout this report.

Each PRD Panel contains a number of Focus Areas. For example, Panel 1 contains the four Focus Areas: Car demo; Bus demo; Material Handling Vehicle (MHV demo); other. Wherever possible, the nomenclature used within the database established in this study has been consistent with the nomenclature used to define the Focus Areas, although it should be noted that the Focus Areas have also varied from year to year.

Although the database has a hierarchical structure, it has been designed with sufficient flexibility in mind to incorporate future projects or changes in focus of the programme. It would also be possible to expand the hierarchy to incorporate keywords at a finer level of detail. However, the structure used has been deemed suitable for purpose at the current time by the author of this report and the Knowledge Manager of FCH 2 JU.

Table 1: Programme Review Day Panels – Names and Topics

PILLAR/ACTIVITY	PANEL NAMES	TOPICS
Transport	1 - Trials and Deployment of Fuel Cell Applications	Projects targeting the demonstration and proof of concept (PoC) of FCH applications in the transportation pillar
	2 - Next Generation of Products	Basic and applied research projects tackling subjects related to the transportation pillar
Energy	3 - Trials and Deployment of Fuel Cell Applications	Projects targeting the demonstration and PoC of FCH stationary heat and power applications in the energy pillar
	4 - Next Generation of Products	Projects targeting the demonstration and PoC of FCH stationary heat and power applications in the energy pillar
	5 - Hydrogen for Sectorial Integration	All projects addressing hydrogen production, distribution and storage issues
Cross-cutting	6 - Support for Market Uptake	Projects addressing cross-cutting issues

Source: JRC based on information obtained from the FCH JU, 2019.

2 Methodology

Projects have previously been classified according to a number of different systems e.g. according to PRD panel, FCH 2 JU objectives which they address, and so on. The object of the keywords exercise is to combine the previous classifications of projects with keywords related to the technologies used. This includes a number of fixed and free keywords.

Keywords have been defined based on the Project Abstracts (and other publicly available information where required to complete the hierarchical structure) of all 244 Projects under FP7 and Horizon 2020.

Firstly, a manual review of all project abstracts was performed to determine a set of keywords for each project. A maximum of 16 keywords per project were determined during this process. Once these keywords had been collated, it became clear that there were two general types of keyword:

(i) keywords relating to a technology (e.g. SOFC) or application (e.g. stationary; CHP). These were defined as the **Project Topics**

(ii) keywords relating to the level at which the technology is being developed (e.g. materials; component; system) and the stage of that development (research; proof-of-concept; demonstration). These were used to define a **Project Class**.

For the keywords related to Project Topic a hierarchical structure was created in order to have a consistent classification of keywords across all projects. This will be discussed in detail in Section 3.1. For the keywords related to Project Class, a further classification was required in order to show the relationship between the Keyword Classifications and the PRD Panels. The Project Class will be defined in Section 3.2 whilst the relationship between the Panels and the Keyword Classifications is shown in Section 3.3. The use of a hierarchical structure was necessary to ensure consistent assignment of Keywords for projects within a given panel.

In addition to the Keyword components, the database also contains the following information:

- Project Identifier
- Project Acronym
- Start/End dates; Duration
- Budget; EC contribution (by pillar)
- Call; Call date
- FCH 2 JU Objective (these objectives are taken from Article 2 of the Council Regulation (EU) No 559/201449 of 6 May 2014 that established the FCH 2 JU [3]; the Programme Office has defined the most relevant objective addressed by each project)
- PRD Panel
- Technology Readiness Level (Start and Target) for Horizon 2020 Projects

In principle, the database can be expanded to include further relevant components. Furthermore, to provide more flexibility a migration from Excel to Access is underway.

3 Classification Structure

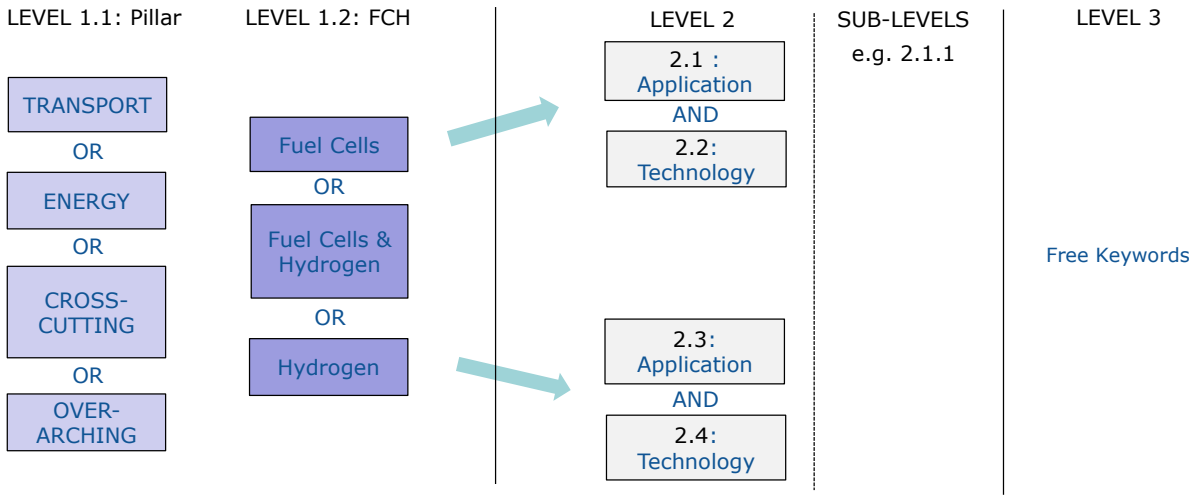
3.1 Classification by Project Topic

Figure 1 shows a schematic, which presents the high level structure of the Project Topic component of the database. Each Project Topic has been given a Keyword Level. The higher levels have been classified according to Pillar (Level 1.1) and whether they address a Fuel Cell or Hydrogen technology, or both (Level 1.2). Note that four projects to date have the classification "over-arching" for Keyword 1.1 as they are research or demonstration projects which receive funding from both Energy and Transport pillars.

At the next level (Level 2.1) the specific primary Application (e.g. Stationary FC; H_2 Production) is given; i.e. this means the main application that is the focus of the project. In the case of Fuel Cells, a sub-application (Level 2.1.1) is included (e.g. Cars). A related primary technology (e.g. PEMFC; Electrolyser-SOE) is given in Level 2.2; by primary technology this means the key technology that is the focus of the project. It should be noted that, wherever possible, the naming of these classifications is consistent with the naming used for the relevant Focus Areas used within the PRD. Lists of entries currently used for these fixed keywords are given in the Annex.

At Level 3, there is the possibility to include up to 10 free keywords. These can be either keywords at a higher level of detail than those given at level 2, or alternatively a technology or application which is touched upon by the project, but is not the primary focus. N.B. Further sublevels could be added in the future to give a finer structure should there be sufficient projects on a particular topic to warrant it.

Figure 1: Overview of the Attribution by Project Topic



Source: JRC, 2019.

3.2 Classification by Project Class

Keywords providing information about the Project Topic (including the Technology and Application) are useful in defining the content of a project. However, keywords can also deal with the stage of the project within the overall development of the technology. For example, recurring keywords such as "R&D; Materials; Component; Prototype; Proof of Concept" suggested a project in the earlier stage of development, whilst recurring keywords such as "System; Field Test; Demonstration; Plant; End-User" suggested a project much closer to real-world application. Cross-cutting projects often involved keywords such as "Education, Safety, Pre-normative Research, Protocols, Standards".

Therefore, in order to fully classify each individual project, a Project Class was defined as shown in Table 2. Six project classes (A-F) were used to define the projects from Panels 1-5 with the aim to capture the range of activities undertaken in that project. In general, Panels 1 and 3 (Trials and Deployment of Fuel Cell Applications) were assigned to Project Class C or D, whilst projects from Panels 2 and 4 (Next Generation of Products) were assigned to Project Class A or B. A few projects from panels 1-4 were assigned to Class E (manufacturing) or Class F (diagnostics). Projects from Panel 5 could be assigned to any of Project Class A-F. Projects from Panel 6 were generally assigned to one of the classes G-K. Note: The most applicable Project Class was assigned to each project. Multiple assignments to an individual project were not permitted.

Table 2: Definitions of Project Class

Class	Project Class
A	Fundamental Research
B	Research to Prototype (Testing of a Technology Component)
C	Technology Validation via Field Test (Field test of a technology in a full System environment)
D	Large Scale Demonstration
E	Manufacturing
F	Diagnostics
G	PNR - RCS
H	Socio-economics
I	Education
J	Sustainability
K	Safety

Source: JRC, 2019.

It should be noted that the allocation of a Project Class is subjective and not ideal, but at this stage is necessary to provide a descriptive classification of projects (to a greater degree of detail than simply "Research" or "Demonstration") to enable to demonstrate some overall trends. Ideally, the Project Class could be replaced, for example, using the Technology Readiness Level (TRL). This has been attempted for Horizon 2020 projects, where the initial and target TRL levels are defined within the calls, and is presented in Section 5. However, even in this case, a TRL range is often given in the call and multiple technologies investigated within a given project may be at different TRL levels. Furthermore, some projects may only attempt to further a technology by a single TRL level whereas other projects may be trying to progress a technology 3 or even 4 levels. Therefore, it is often difficult to make a clear connection between Project Class and TRL.

3.3 Mapping of Projects using Keyword Classifications, according to PRD Panel

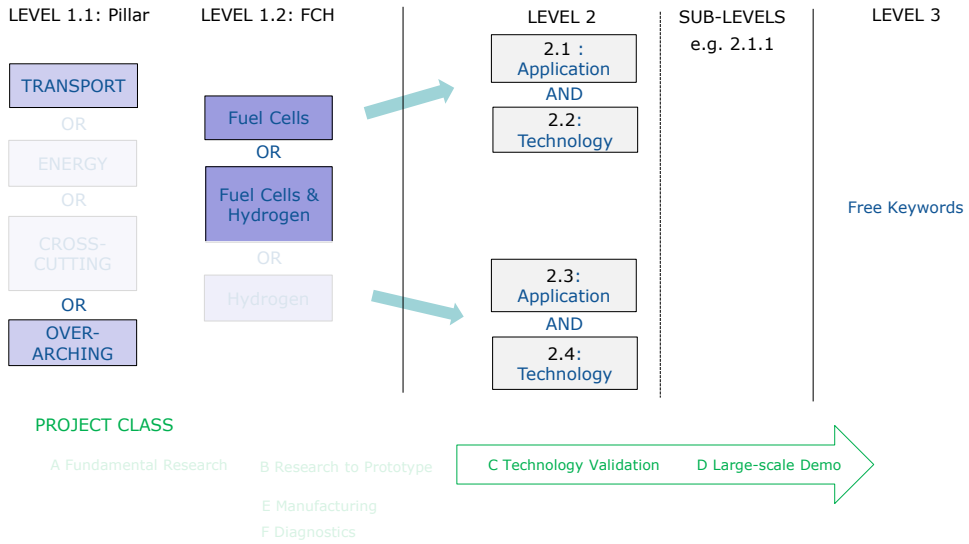
One aim of this exercise was to be able to produce information suitable for analysing FCH 2 JU progress not only at a Program level but also at Panel level. Therefore, for consistency, it was important that the structure can be easily related to the Panels involved. With this in mind, the following six figures show how the projects within a given panel map onto the Keyword Database structure. In practical terms, this means that an ongoing or finished project belonging to a particular panel should, as a minimum, have entries in the database for the Keyword Topics highlighted, plus a corresponding Project Class as indicated. Conversely, for future projects, it should be possible to propose an attribution of a project to a particular PRD panel based on the keywords extracted from the project summary. In Figure 2 to Figure 7 a schematic for each PRD Panel is provided, showing which fields within the hierarchy should be completed for that particular panel. Figure 2 shows the schematic for Panel 1 – Trials and Deployment of Fuel Cells Applications (Transport). Naturally, these fall under the Transport pillar (Level 1.1), and the projects may either relate to a Fuel Cell technology or FC&H (Level 1.2). This is because the projects in this Panel often deploy fuel cell vehicles and develop the Hydrogen Refueling Stations (HRS). An example for a Panel 1 project would be:

Hylift-Europe:

1.1	Transport		
1.2	Fuel Cells and Hydrogen		
2.1	Transport	2.1.1	MHV
2.2	PEMFC		
2.3	H_2 Distribution		
2.4	Refueling Infrastructure		
3	HRS; Airport Tow Tractors; Early Markets		
D	Large Scale Demonstration		

Note that some duplication is seen for this example as the Pillar and highest level of application (2.1) are both Transport. This is necessary because of Over-arching projects which would be 1.1. Overarching; 2.1 Transport, Stationary.

Figure 2: Panel 1 – Trials and Deployment of Fuel Cell Applications (Transport)



Source: JRC, 2019.

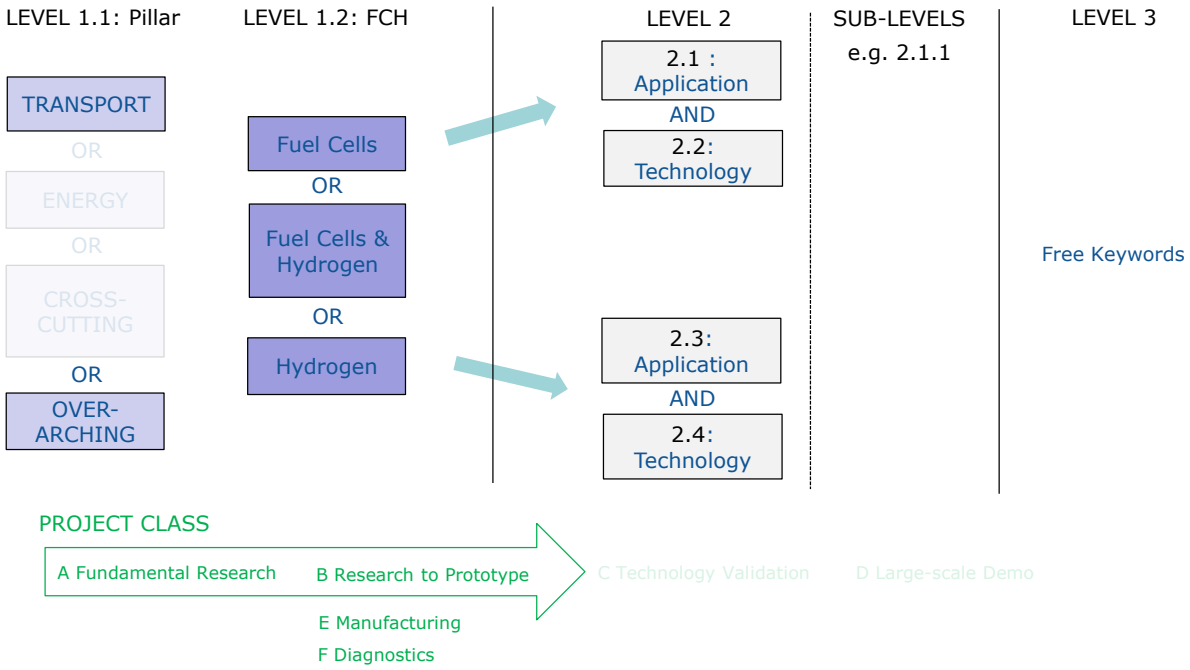
Figure 3 shows the schematic for Panel 2 – Next Generation of Products (Transport). Again, these projects come under the Transport pillar (Level 1.1), and the projects may either relate to a Fuel Cell technology or FC&H or Hydrogen (Level 1.2) as they may relate to fuel cells for use in automotive applications, hydrogen dispensing (for example) or wider research covering both areas.

An example for a project in Panel 2 would be:

COMPASS:

1.1	Transport		
1.2	Fuel Cells		
2.1	Transport	2.1.1	APU
2.2	SOFC		
3	APU-Car; Metal-support; Automotive Testing; Range Extender; System integration		
B	Research to Prototype		

Figure 3: Panel 2 – Next Generation of Products (Transport)



Source: JRC, 2019.

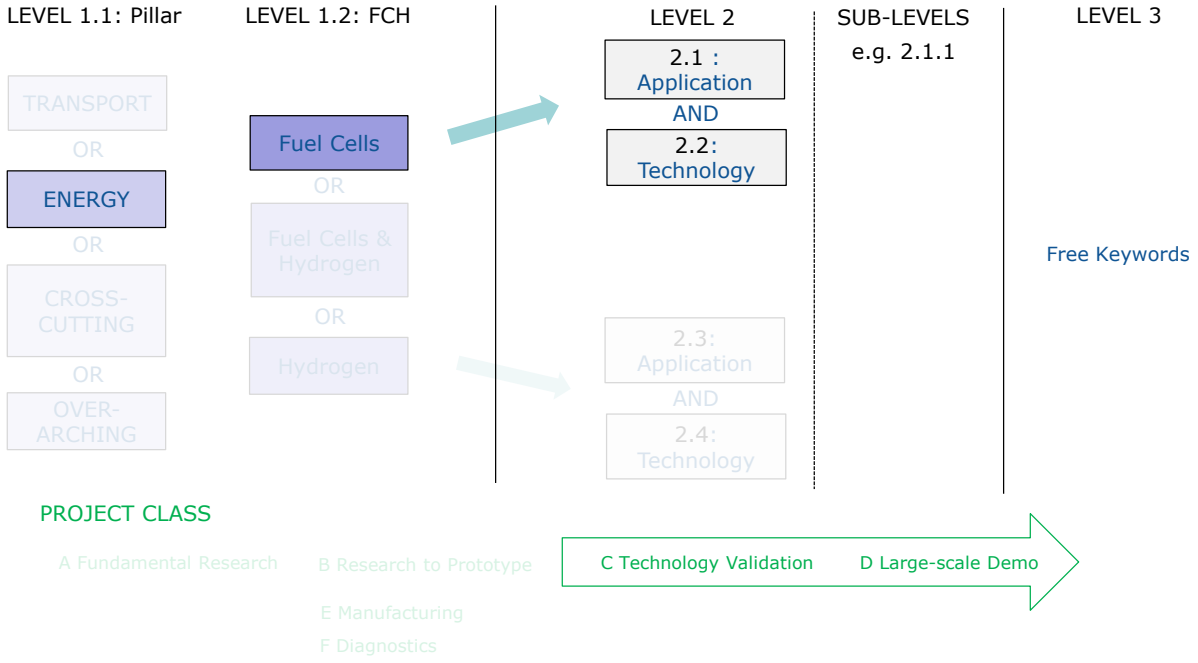
Figure 4 shows the schematic for Panel 3 – Trials and Deployment of Fuel Cells Applications (Energy). These fall under the Energy pillar (Level 1.1), and the projects generally relate specifically to a Fuel Cell technology (Level 1.2).

An example for a project in Panel 3 would be:

FLUMABACK:

1.1	Energy		
1.2	Fuel Cells		
2.1	Stationary	2.1.1	Off-grid/CHP
2.2	PEMFC		
3	Fluid Management; Reliability; Lifetime; Cost; Recirculation Pumps; Humidifier; Heat Exchanger; Component Integration		
C	Technology Validation via Field Test		

Figure 4: Panel 3 – Trials and Deployment of Fuel Cell Applications (Energy)



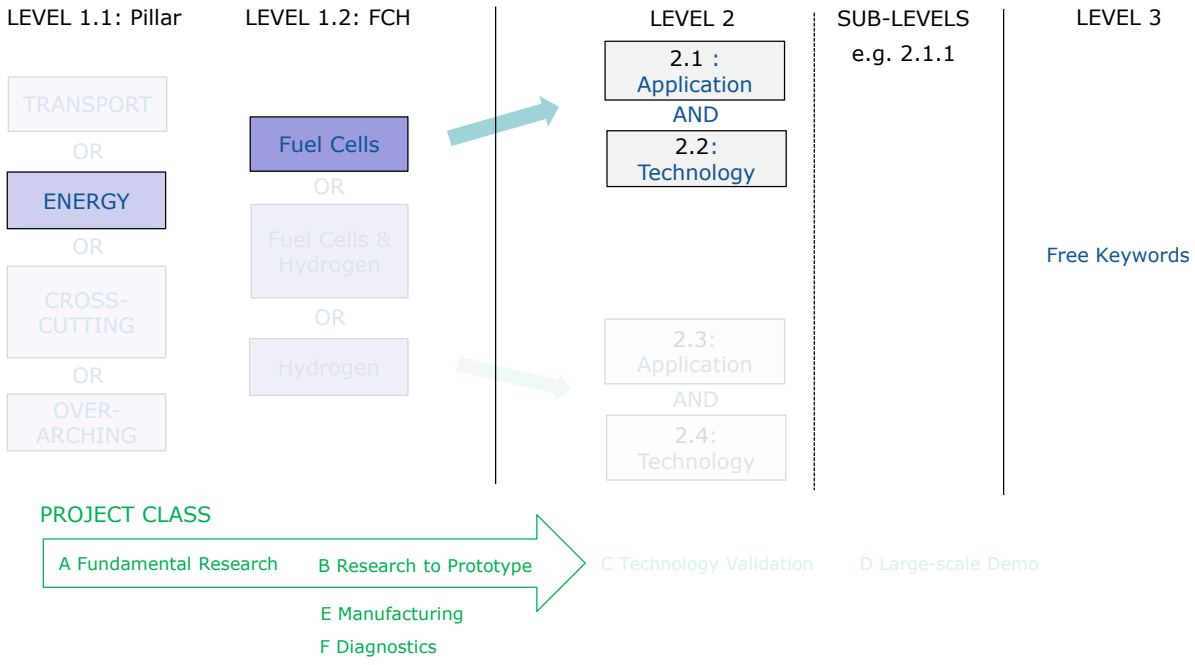
Source: JRC, 2019.

Figure 5 shows the schematic for Panel 4 – Next Generation of Products (Energy). Naturally, these fall under the Energy pillar (Level 1.1), and the projects generally relate to a specific Fuel Cell technology (Level 1.2). An example for a project in Panel 4 would be:

Cell3Ditor:

1.1	Energy		
1.2	Fuel Cells		
2.1	Stationary	2.1.1	Commercial Size CHP
2.2	SOFC		
3	3D-Printing; Two-step process; Printing; Sintering		
E	Manufacturing		

Figure 5: Panel 4 – Next Generation of Products (Energy)

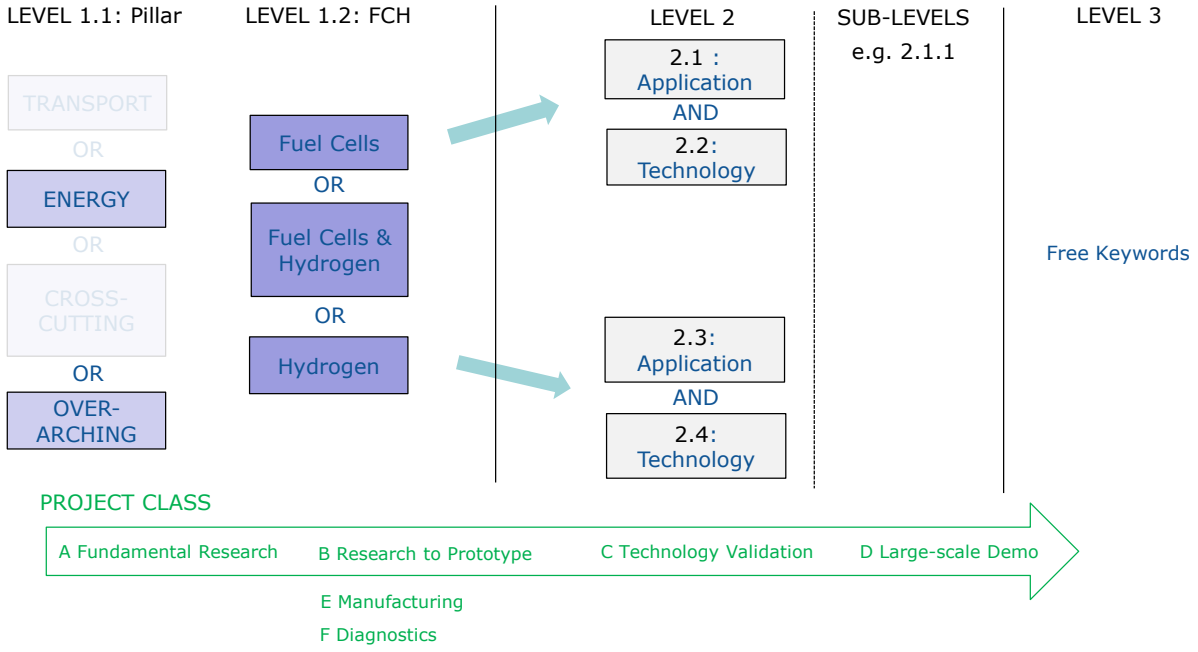


Source: JRC, 2019.

Figure 6 shows the schematic for Panel 5 – Hydrogen for Sectorial Integration. These projects are under the Energy pillar (Level 1.1), and the projects obviously relate primarily to hydrogen (Level 1.2). An example for a project in Panel 5 would be:

RESELYSER:		
	1.1	Energy
	1.2	Hydrogen
	2.3	H_2 production
	2.4	Alkaline Electrolyser
	3	Membrane; Electrodes; Design; Efficiency
	B	Research to Prototype

Figure 6: Panel 5 – Hydrogen for Sectorial Integration



Source: JRC, 2019.

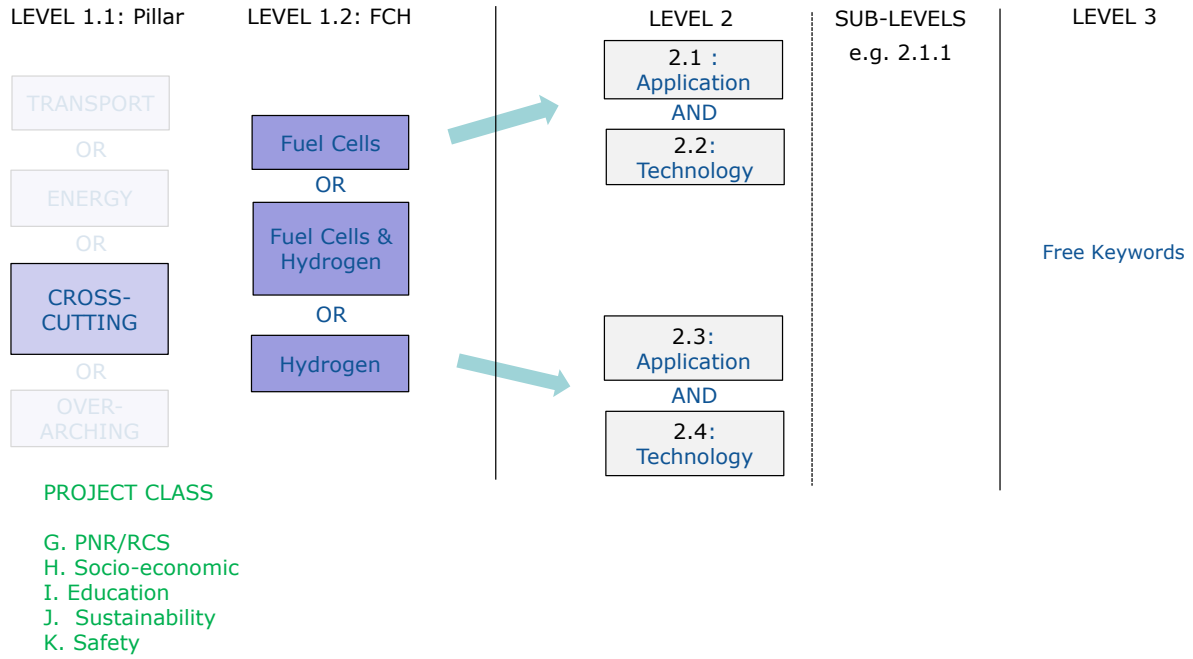
Note that the only projects with required entries for fields 2.1 and 2.2 will be the over-arching projects.

Figure 7 shows the schematic for Panel 6 – Support for Market Uptake. This panel covers Cross-cutting activities which can cover either or both of the pillars. An example for a project in Panel 6 would be:

HYCORA:

1.1	Cross-cutting		
1.2	Fuel Cells and Hydrogen		
2.1	Transport	2.1.1	Automotive
2.2	PEMFC		
2.3	H_2 distribution, H_2 Purity		
2.4	Refueling Infrastructure		
3	Contaminants; Risk Assessment; Hydrogen Purification; Reforming; Quality Assurance		
G	PNR/RCS		

Figure 7: Panel 6 – Support for Market Uptake



Source: JRC, 2019.

4 Examples of Use of the Keyword Database to Observe Trends

4.1 Introduction

This section provides examples of information that can be retrieved from the database. In general, bar charts are provided showing the cumulative levels of EU funding contribution against the start year of the projects (unless stated otherwise). This is first performed for high level classifications such as the Pillar and PRD Panel, and then for lower level keywords for specific technologies and applications. The projects included are the 244 which have been started to date under the FCH JU.

It should be noted that as only public information was used, a simple association between the total project contribution and the corresponding keyword is made. No weighting has been used, for example, taking account of how much of that particular project's budget was spent working with a particular technology. It could be foreseen to perform such an activity in the future, where the funding per work package is investigated in more detail, however this would be a very complex and time-consuming exercise and require the use of confidential documents. However, in a few cases where it is clear that two technologies have been used in fairly equal amounts for a project, e.g. DON QUICHOTE where both PEM and alkaline electrolysers were operated, then a 50:50 split in the funding contribution between these technologies has been made. A split was also performed for Over-arching projects where the ratio of funding distribution provided to the Transport and Energy pillars was included in the calculations.

In general, however, the information presented indicates how much EU funding was provided for a project with a particular keyword, not how much money was spent on that particular technology.

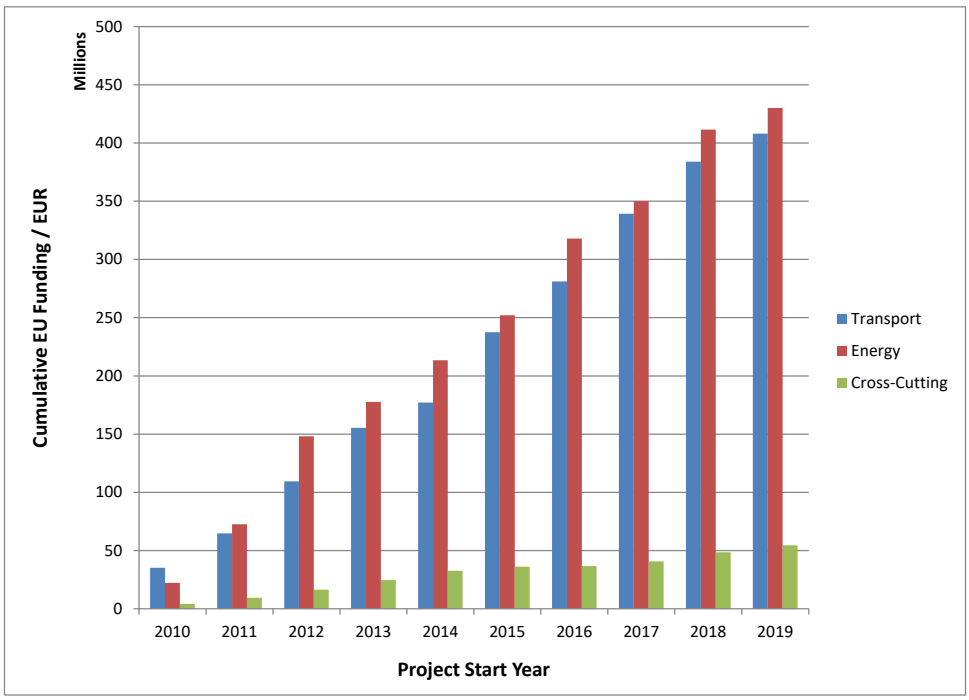
4.2 High Level

(Pillar, Objective, Panel)

In Figure 8 the cumulative EU funding for FCH 2 JU projects across the three pillars is shown. The funding provided to Over-arching projects has been split between the Transport and Energy pillars according to the ratio provided by the Programme Office, for that particular project. As can be seen, the funding has been very evenly split over the years between the Transport and Energy themes. A smaller contribution corresponding to approximately 5-6% of the total budget has been spent on cross-cutting activities.

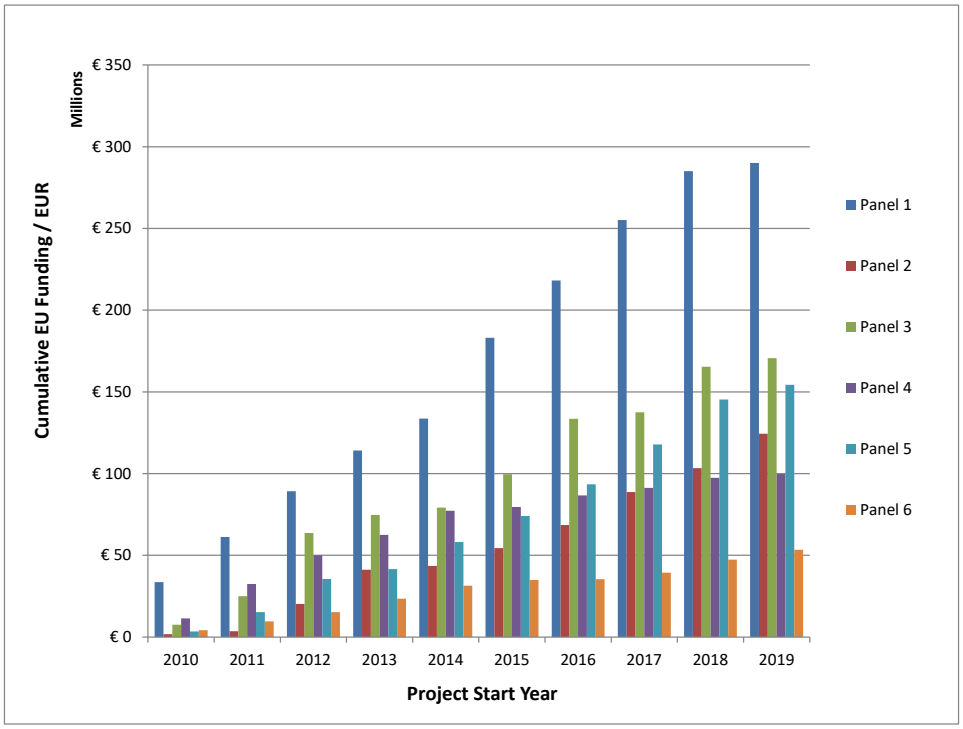
In Figure 9 the cumulative EU funding contribution is shown per project start year for the six different panels of the PRD. It can be seen that the largest recipient of EU funds has been Panel 1: Trials and Deployment of Fuel Cell Applications (Transport). One point to note is that around the point of the transition from FP7 to H2020, a change in focus is expected, away from fundamental research and towards more application-ready technologies. This is clearly seen for stationary applications as the degree of funding to Panel 4 levels out after 2014. The same cannot be said, however, for Panel 2 regarding research activities for transport applications, where a steady increase year on year is observed from 2014-2018. It should also be noted that for PRD 2018 a group of six historical FP7 projects (FC GEN, DESTA, SAPIENS, PURE, SAFARI, HYCARUS) were transferred from Panel 1 to Panel 2. For the purpose of this plot, they have been retained in their historical Panel 1, however, this transfer would increase the contribution to Panel 2 by a further €17.8 million at the expense of Panel 1. Panel 5 has also received a significant proportional increase in funding during Horizon 2020 compared to FP7.

Figure 8: Cumulative EU funding according to Pillar against the start year of the projects



Source: JRC, based on public data from the FCH JU, 2019.

Figure 9: Cumulative EU funding according to PRD Panel against the start year of the projects



Source: JRC, based on public data from FCH JU, 2019.

In Article 2 of the Council Regulation (EU) No 559/201449 of 6 May 2014 [1, 3] that established the FCH 2 JU, five main technical objectives were established. The FCH JU has previously classified the projects according to which of these objectives they primarily address. The objectives are:

1. to reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies;

2. to increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs;

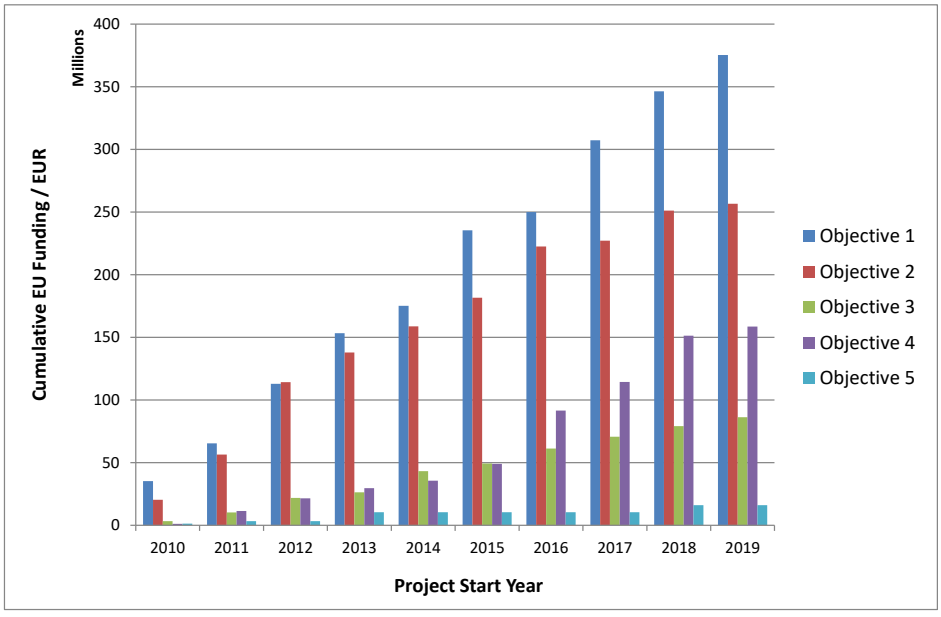
3. to increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market;

4. to demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources;

5. to reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements.

The classification performed by the FCH JU does not take account of any secondary objectives of projects as it was a 1-to-1 attribution. It should also be noted, that for projects prior to 2014, these objectives have been assigned *post hoc*. Whilst this is not strictly a part of the keywords exercise, the data has been included for completeness. The cumulative level of the EU funding contribution against the project start year for these objectives is shown in Figure 10. It can be seen that the largest contribution has been towards achieving Objective 1 followed by Objective 2. It can also be seen that from 2014 (and the onset of Horizon 2020) a significant relative increase in the level of funding for projects supporting Objective 4 occurs. It should be noted that relatively few projects to date have had the primary objective of reducing the use of critical raw materials.

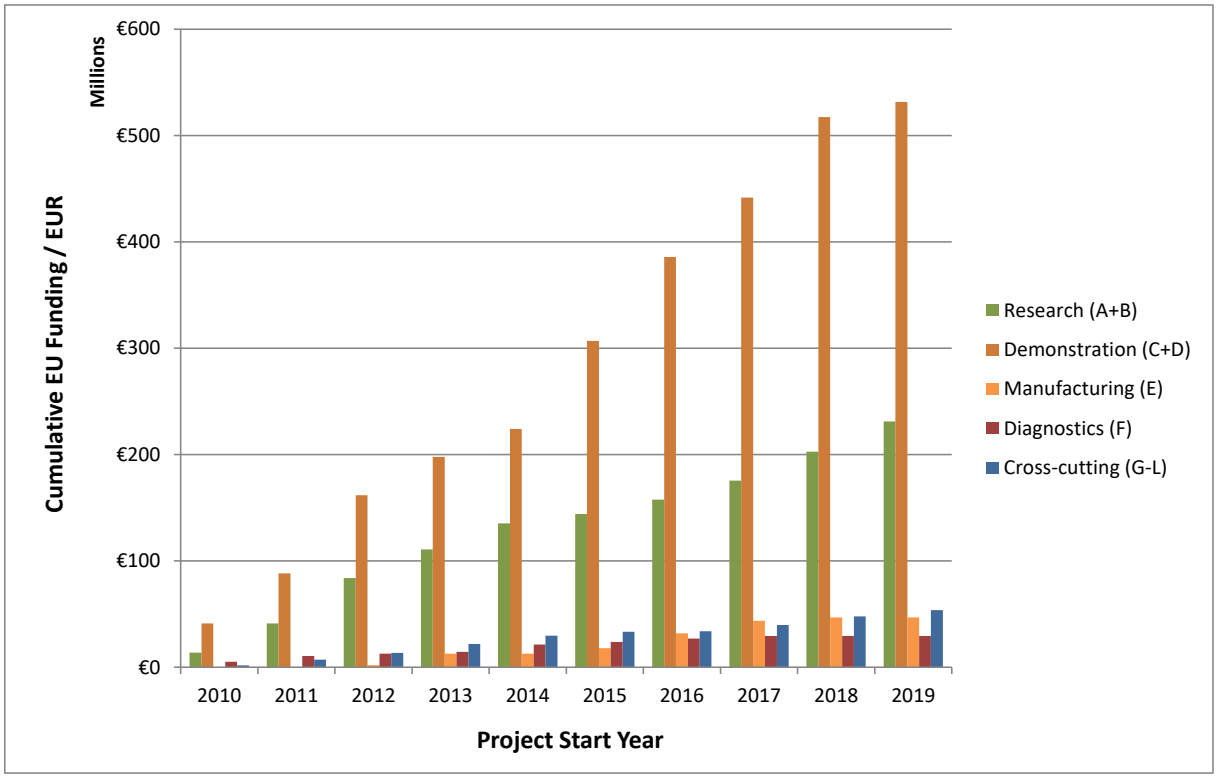
Figure 10: Cumulative EU funding according to the FCH 2 JU Objectives against the start year of the projects



Source: JRC, 2019, based on public data from FCH JU.

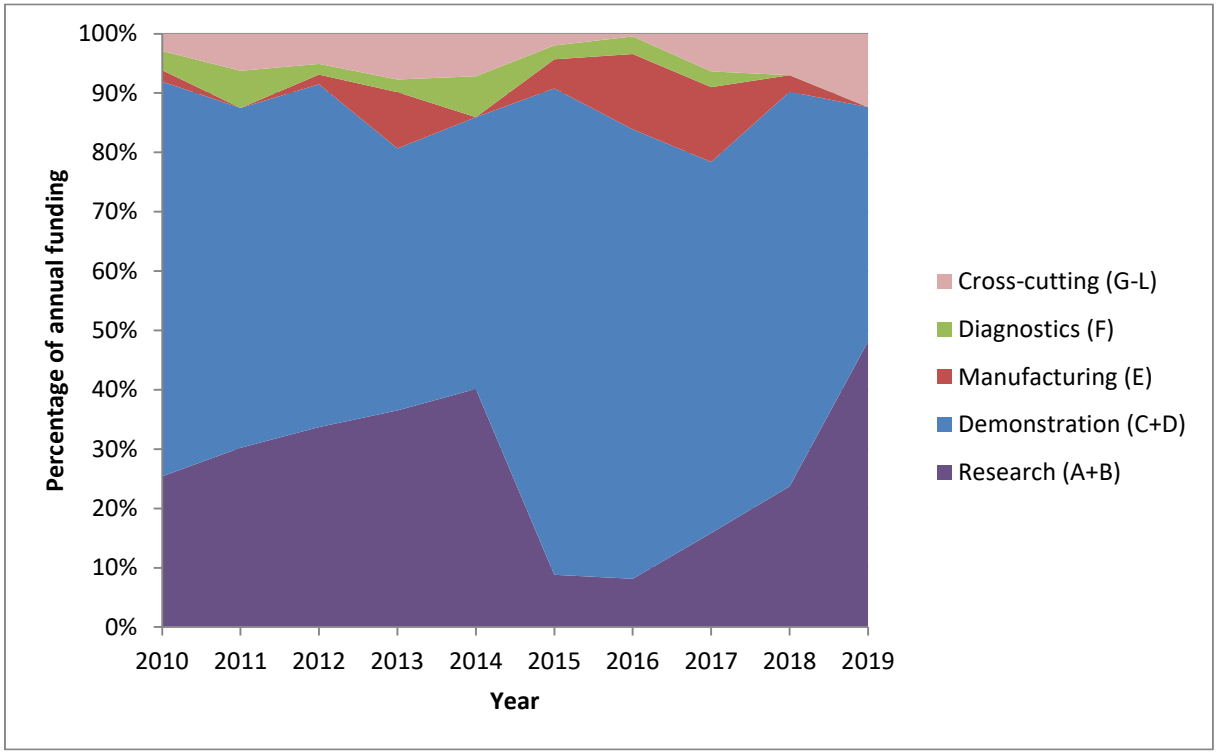
Finally, in this section, the new definition of Project Class will be considered. The inclusion of a Project Class was deemed necessary in order to fully map the projects onto the corresponding PRD panels (as shown in Section 3). This provides some interesting additional information as shown in Figure 11. From this figure it is possible to see how the level of funding for research has levelled out after the transition from FP7 to H2020 in 2014 with a larger focus on demonstration and manufacturing projects. It should be noted that for the purpose of the PRD panels, the manufacturing projects are usually classed as "research" by the FCH 2 JU. It is clear, however, that the emphasis has changed from basic materials research to manufacturing process research in recent calls. However, it can be seen that there has been a recent upturn in the level of funding for Class A+B projects (from 2016-2019) mainly due to an increase in funding for projects in Panel 2. This is emphasised in Figure 12 where the percentage funding per category is shown. A clear drop in contribution towards research funding was observed from 2014 that is being reversed in the last two years. N.B. In Figure 11 and Figure 12 some classes have been grouped together for the purpose of clarity. These additional classes do serve a wider purpose when presenting how the focus of projects has changed over the course of the FCH 2 JU, however, this will not be discussed in more detail here.

Figure 11: Cumulative EU funding according to the Project Class against the start year of the projects



Source: JRC, 2019, based on public data from FCH JU.

Figure 12: Relative percentage of EU funding contributions per year according to Project Class and the start year of the project



Source: JRC, 2019, based on public data from FCH JU.

4.3 Technology / Application Level

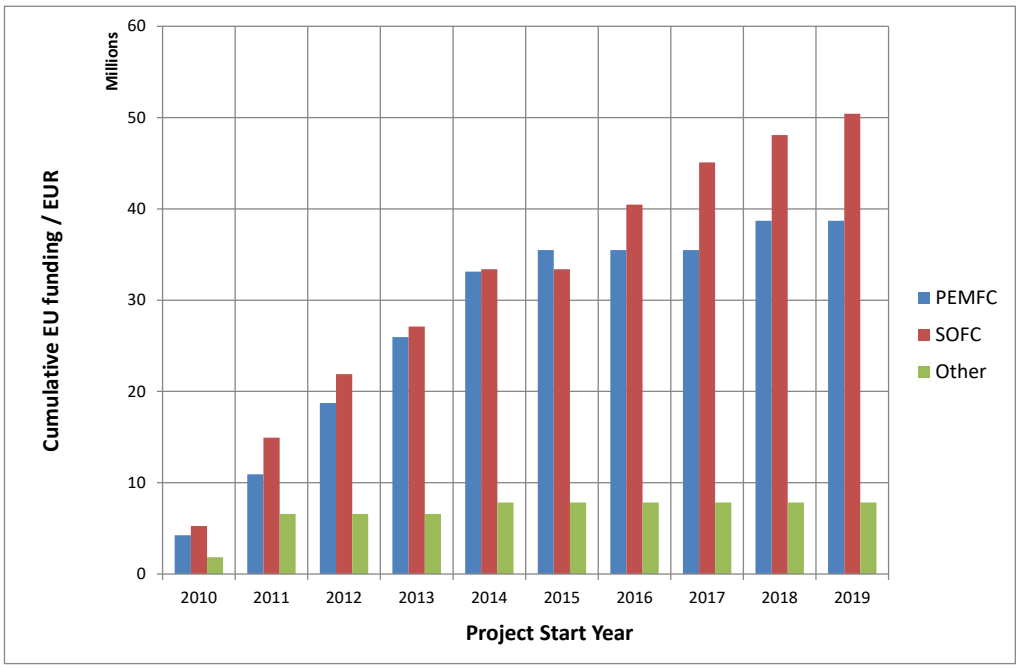
As shown in the overall structure of the keyword database shown in Figure 1, after the high level classifications (at Level 1) there are a number of structured classifications at Level 2 relating to the technology and application focuses of the projects.

An example of how this can be used to see trends in the degree of expenditure regarding different technologies can be seen in Figure 13. In this figure, the cumulative level of the EU funding relating to the fuel cell technology used for projects placed under Panel 3 (Trials and Deployment of Fuel Cell Applications - Energy) is shown, versus the start year of the project. In this case, two filters have been combined in the database (namely, the Panel and Fuel Cell Technology). As a significant quantity of the EU contributions towards FCH 2 JU projects are given to transport projects (both demonstration and research) where PEMFC predominate, it is necessary to isolate the stationary project data where multiple technologies are used. When this is done, it can be seen from Figure 13 that roughly equal sums have been spent historically on demonstration projects involving PEMFC and SOFC technologies for stationary applications. Figure 14 shows the equivalent graph for Panel 4 (Next Generation of Products - Energy). This shows a similar trend until 2014 when there is a clear divergence between the spending on PEMFC and SOFC. It is clear that research projects involving SOFC technology continued to be funded at a similar rate, whilst the spending on research projects related to PEMFC in stationary applications was significantly reduced for Horizon 2020. These graphs also show that for stationary applications, the EU is clearly focussing on these two technologies and that only limited funding has been spent on other fuel cell technologies (e.g. MCFC, PAFC or AFC).

Figure 13: Cumulative EU funding according to the primary Fuel Cell Technology investigated against the start year of the projects - data shown for Panel 3 projects only

Source: JRC, 2019, based on public data from FCH JU.

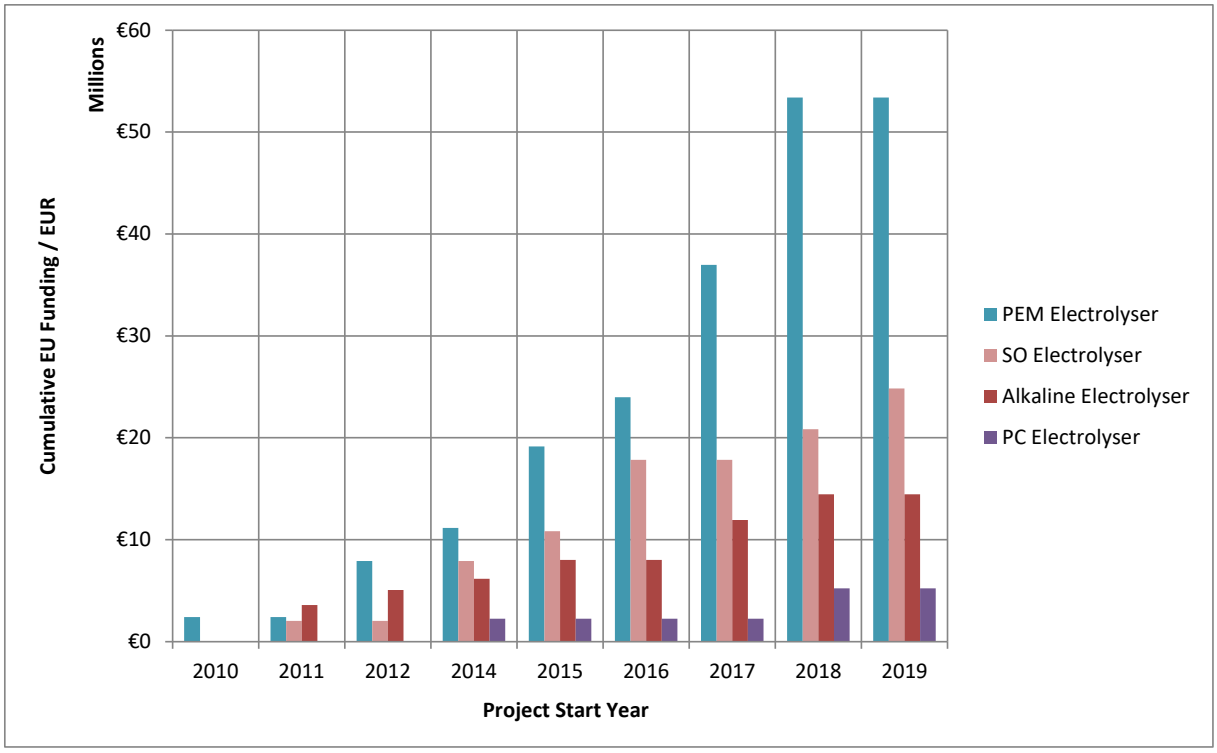
Figure 14: Cumulative EU funding according to the primary Fuel Cell Technology investigated against the start year of the projects - data shown for Panel 4 projects only



Source: JRC, 2019, based on public data from FCH JU.

Another example of the analysis is given in Figure 15. Here, the electrolyser technology funded within Panel 5 projects (Hydrogen production, distribution and storage: research and validation) of the FCH 2 JU is presented. A clear focus on PEM electrolysers is visible in recent years with the level of investment being double that invested in SOE projects (it should be noted that SOE is generally at a much earlier stage of development than PEME). A smaller amount still is being invested in alkaline electrolyser projects, although this can be attributed to the fact that AE are already a widely implemented and commercial technology. A further, lower TRL technology, the Proton Ceramic Electrolyser (PCE) has also received funding via two projects.

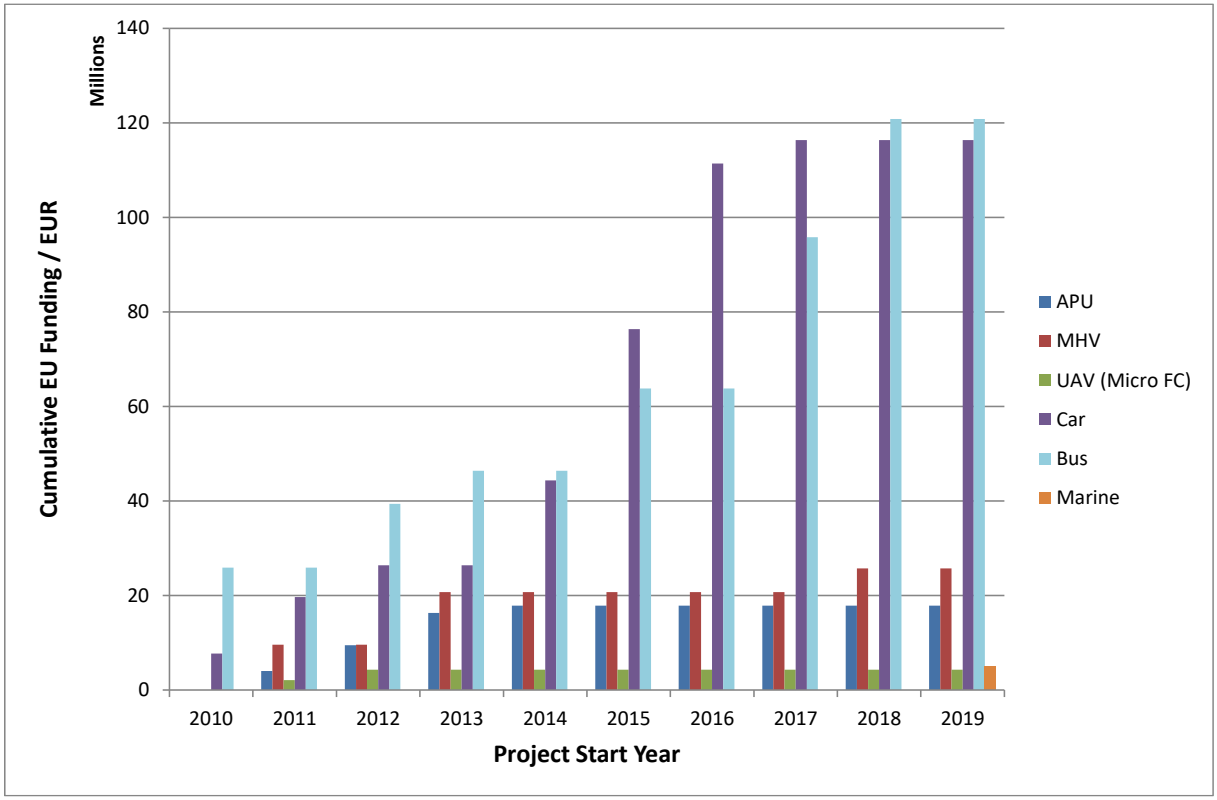
Figure 15: Cumulative EU funding according to the primary Electrolyser Technology investigated against the start year of the projects - data shown is for Panel 5 projects only



Source: JRC, 2019, based on public data from FCH JU.

As a final example, Figure 16 shows the degree of EU funding towards the different applications for projects classed under Panel 1 (Technology validation in transport applications). Here, unsurprisingly, the main beneficiaries are car and bus demos. It is interesting to see how the funding has appeared to oscillate between the two main applications over the period from 2010-2018, although to date the spending on the two applications appears to be almost equal. Furthermore, it can be seen that from 2013, other applications (MHV, APU and UAV) have only received very limited funding compared to the two main applications.

Figure 16: Cumulative EU funding according to the primary Application against the start year of the projects - data shown is for Panel 1 projects only



Source: JRC, 2019, based on public data from FCH JU.

This section has provided some examples as to how trends in spending for particular technologies or applications can be tracked using keywords attributed to those projects. This uses keywords within "Level 2" of the initial database design. It should be noted that the database includes a third level corresponding to Free Keywords which do not fall under any of the categories foreseen in the higher level classifications, or which concern secondary technologies used in the projects. Currently, not a great deal of use has been made of this Free Keyword level. One reason is that Excel is not a particularly appropriate tool for dealing with multiple entries in an individual field. The migration of the database to Access (which is ongoing) provides additional functionality which makes it easier to deal with these multiple entries. However, an additional point is that these free keywords are less useful when trying to determine trends in funding of particular activities, mainly because there are not sufficient projects with a particular Level 3 keyword to determine a trend. Alternatively, further fine structuring of the hierarchy to give more sub-levels prior to the Free Keywords could also be performed where it is seen to be of use.

5 Technology Readiness Level

The Technology Readiness Level (TRL) is a way of estimating the maturity of a technology. It was originally devised by NASA in the 1980s and the European Commission advised its use in EU-funded research and innovation projects from 2010, with it becoming officially adopted for Horizon 2020 in 2014. The definitions of the TRL levels used in the General Annex of the Horizon 2020 Work Programme [4] are:

TRL 1 – basic principles observed

TRL 2 – technology concept formulated

TRL 3 – experimental proof of concept

TRL 4 – technology validated in lab

TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 7 – system prototype demonstration in operational environment

TRL 8 – system complete and qualified

TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

For all FCH 2 JU calls issued under Horizon 2020, a TRL level is linked to the call. In some cases this may be a range (e.g. a project may begin at TRL 3-4 and have a target of TRL 5-6) and in other cases very specific start and target TRLs are given as requirements for the call. Whilst it was not strictly part of the Keyword exercise, at the request of FCH 2 JU, the start and target TRL were added to the database for the Horizon 2020 projects. The TRL levels were attributed to the projects by the following methodology:

1) Where the TRL start and target levels were given specifically in the call (as a single digit rather than a range) then these values were used

2) Where the TRL value was only provided as a range in the call, the Project Description of Work was referred to, in order to determine whether specific TRL values were provided by the Project Consortium. It should be noted that this is the only occasion within this document where non-public information was used.

3) Where the TRL value was only provided as a range in the call, and where the Project Description of Work did not provide a specific TRL level for the project, an assignment was made based on the project description at the judgement of the author of this report.

It should be noted that in order to provide a single start and target TRL for an individual project, often an oversimplification was necessary. Some projects deal with multiple technologies each at a different stage of readiness, therefore it is difficult to apply a single TRL at project level. In this instance, the TRL level for the main technology focus of the project was chosen. However, it should be noted that the purpose of this exercise is to determine overall trends when dealing with the whole body of projects. It is considered that the approach taken is sufficient for this purpose.

Of the 90 projects which have been started under Horizon 2020, 75 were assigned TRL levels. For some projects, especially Cross-cutting projects, TRL levels are not applicable.

In Figure 17, the start and target TRL levels for all 75 projects are shown. They have been shown according to the Panels in which they have been placed for the PRD process. In general, it had been anticipated that the projects in Panels 2 and 4 which are largely research projects would be addressing lower TRL levels than those in Panels 1 and 3 which are addressing demonstration and deployment. Indeed, the average TRL levels (shown in Table 3) show this trend. However, whilst this is the case for the majority of projects, it is not universally true. Figure 17 demonstrates that the range of start and target TRL levels in particular panels is, in fact, exceptionally broad. This can also be determined from the large standard deviation on the average values in Table 3. It can also be seen from Table 3 that the average project targets an increase in TRL of approximately 2 (this is consistent across all panels).

Table 3: Average Start and Target TRL Levels by Panel

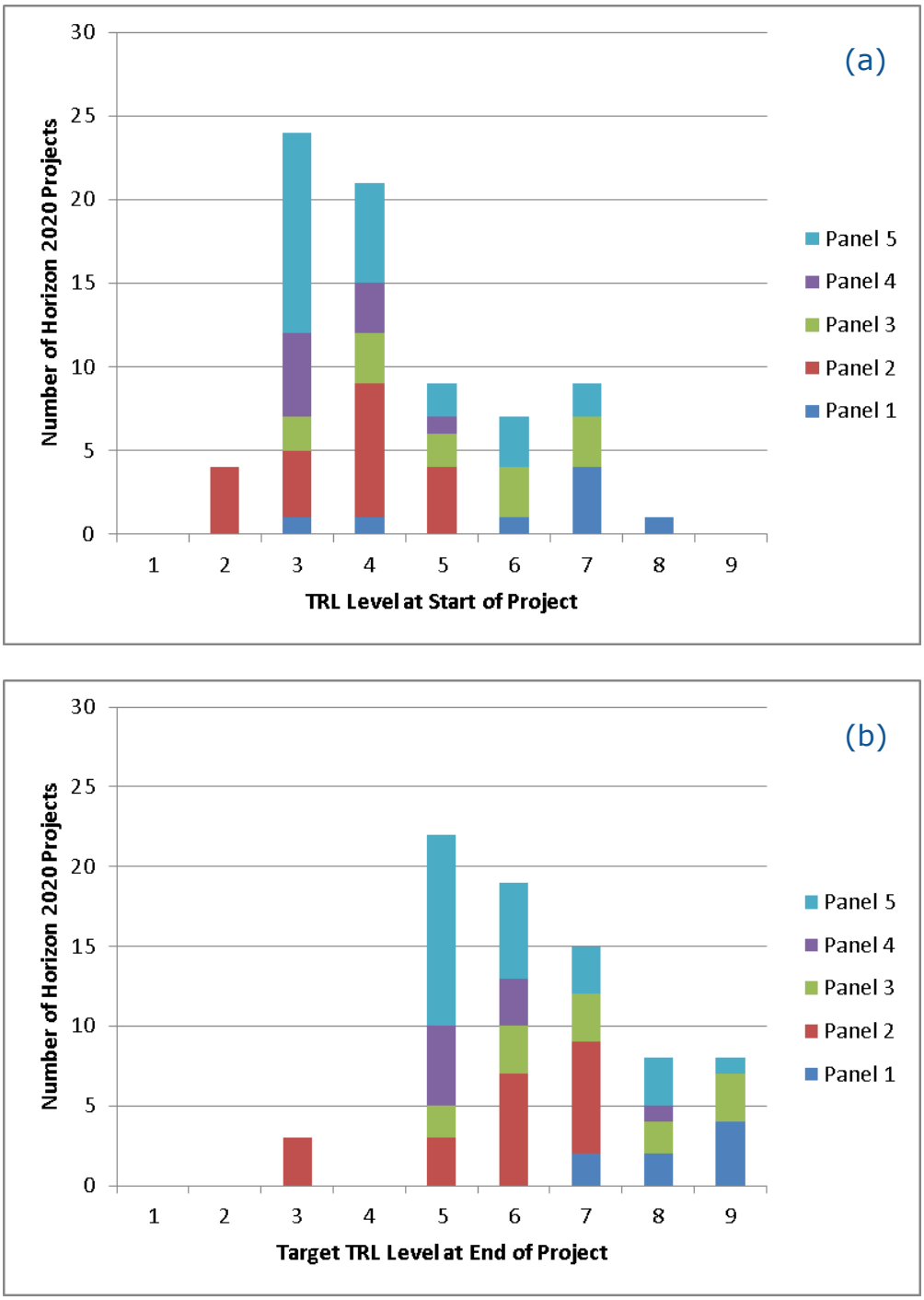
Panel	Number of Projects	Average Start TRL (± standard deviation)	Average Target TRL (± standard deviation)
1	8	6.1 (±1.7)	8.3 (±0.9)
2	20	3.6 (±1.0)	5.8 (±1.4)
3	13	5.2 (±1.5)	7.1 (±1.4)
4	8	3.6 (±0.7)	5.8 (±1.0)
5	26	4.0 (±1.3)	6.0 (±1.2)

Source: JRC, based on public information from FCH JU.

Furthermore, there is a considerably broader range of starting TRLs for projects from the same Panel than was expected. It should be stressed that the general project class and TRL levels are difficult to relate to each other, as some projects are targeting an advancement of only a single TRL whilst others target an increase of 3-4 TRL.

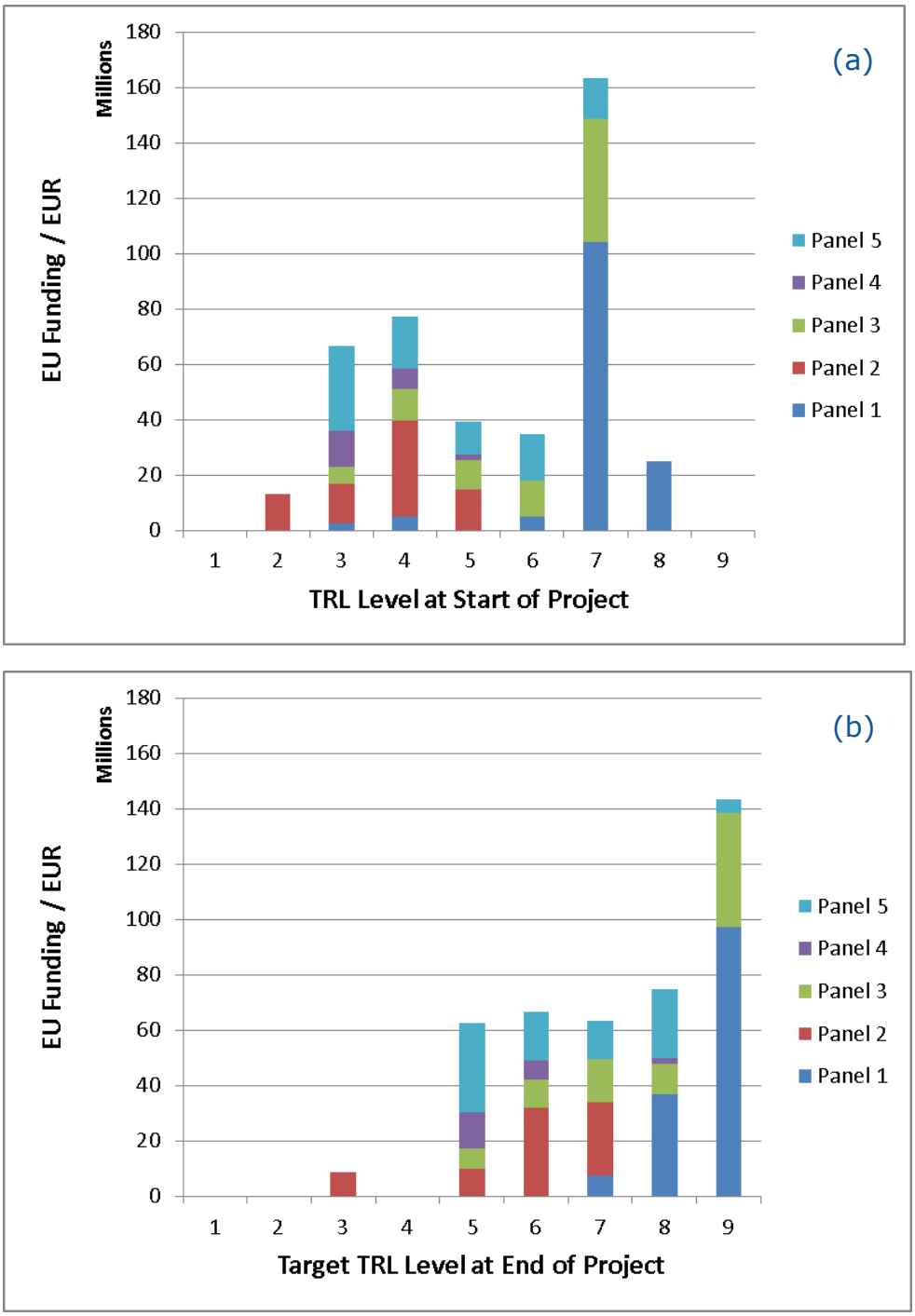
When the data is examined in detail, what is apparent is that there are a large number of projects starting at TRL 3-4 and targeting predominantly TRL 5-6. A second batch of projects starts at TRL 7 and TRL 8-9. From Figure 18, where the same data is expressed in terms of project budget, it can be seen that this second grouping, whilst fewer in number dominate when it comes to budget due to a few large demonstration projects (in particular in Panel 1).

Figure 17: Number of Horizon 2020 Projects with a particular (a) start and (b) target TRL - data shown per Panel



Source: JRC, 2019, based on public information from FCH JU.

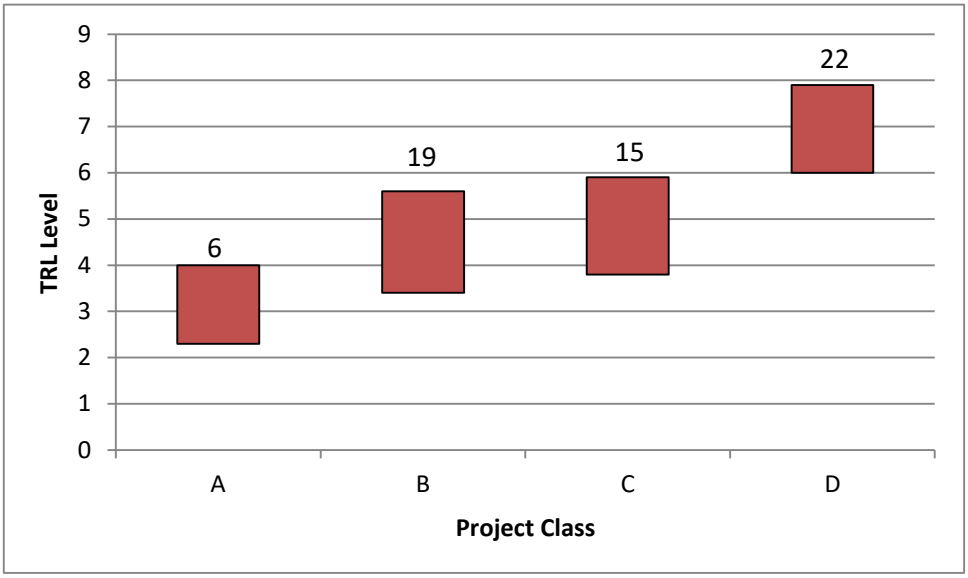
Figure 18: EU funding of Horizon 2020 Projects with a particular (a) start and (b) target TRL – data shown per Panel



Source: JRC, 2019, based on public information from FCH JU.

An additional plot, to look at the relationship between Project Class and TRL level is given in Figure 19. This is looking specifically at the subset of projects that have been assigned a Project Class of A-D. In general, Panels 2 and 4 contain projects from Classes A and B (by definition) whilst Panels 1 and 3 contain projects from Classes C and D. From Figure 19 it is clear that there is not a great deal of difference between Project Classes B and C with regards to TRL levels. This would suggest that the distribution of projects between the Panels is not clearly made on a distinction between "research" and "demonstration" based projects. A clearer future allocation related to the TRL level assignments of the calls could provide more clarity to the purpose of separating the projects according to these panels.

Figure 19: Figure relating Project Class to TRL level for Horizon 2020 projects. The range shows the average start to average end TRL levels; the number above the column shows the number of projects in a particular Project Class.



Source: JRC, 2019, based on public information from FCH JU.

6 Conclusions

A keyword database has been constructed based on the described methodology. The main motivation for this exercise was to observe trends in funding committed to topics, technologies and applications, by the FCH 2 JU.

The keyword hierarchy that has been constructed has been mapped onto the PRD Panels, and could be used to help define to which panel a new project should be allocated. The database can also provide useful supporting data to the ongoing historical analysis, which is trying to determine the overall impact of the FCH 2 JU activities since its inception.

Specifically, the data produced has demonstrated a move away from research activities between FP7 and Horizon 2020 for the Energy pillar. However, this was not observed to be the case for the Transport pillar where the funding for research has increased. Trends in funding for particular technologies and applications have also been provided.

Issues were observed when attempting to relate the projects in particular panels to the Technology Readiness Levels indicated in the Horizon 2020 calls. Whilst on average the TRL levels of Panels 2 and 4 are lower than those of Panels 1 and 3, there is a significant degree of overlap. This warrants further discussion, with regards to the consistency applied to the distribution of projects between Panels.

The database could be used to relate keywords to other parameters on extension of the database. It is believed that this could be assisted by a migration from Excel to Access, to fully utilise database features.

7 Future Work and Outlook

A number of possible future activities can be envisaged with regards to the keyword database.

- The conversion of the database to Access from Excel could provide additional features, including improving the input and output of data (without having to create a new version) and could avoid multiple version at different sites.
- The structured use of the database could assist with the allocation of projects to Panels for new projects.
- Updated figures could be made available for future Programme Review reports
- The database could be used to provide supplementary figures for Historical Analysis reports in order to put the technical reviews in context with the degrees of funding
- Reviewing trends in funding could establish whether particular topics are being funded at an appropriate level.

References

1. '*Fuel Cells and Hydrogen Joint Undertaking*'. Available from: https://fch.europa.eu/.
2. '*Fuel Cells and Hydrogen Joint Undertaking, Multi-Annual Work Plan 2014 - 2020.*' , 2014. Available from: https://www.fch.europa.eu/page/multi-annual-work-plan
3. '*Council Regulation (EU) No 559/201449', 2014.* Available from: *http://ec.europa.eu/research/participants/data/ref/h2020/other/legal/jtis/fch-establact_en.pdf*
4. '*HORIZON 2020 – WORK PROGRAMME 2014-2015 General Annexes*', 2014. Available from: *https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf;*, 2014.

List of abbreviations and definitions

AE	Alkaline Electrolyser
AFC	Alkaline Fuel Cell
APU	Auxiliary Power Unit
CHP	Combined Heat and Power
EC	European Commission
EU	European Union
FC	Fuel Cell
FCH	Fuel Cell and Hydrogen
FCH JU	Fuel Cell and Hydrogen Joint Undertaking
FCH 2 JU	Fuel Cell and Hydrogen Joint Undertaking 2
FP7	Framework Program 7
H2020	Horizon 2020
JRC	Joint Research Centre
MAWP	Multi-Annual Work Program
MCFC	Molten Carbonate Fuel Cell
MHV	Materials Handling Vehicle
NASA	National Aeronautics and Space Administration
PAFC	Phosphoric Acid Fuel Cell
PCE	Proton Ceramic Electrolyser
PEM	Proton Exchange Membrane
PEME	Proton Exchange Membrane Electrolyser
PEMFC	Proton Exchange Membrane Fuel Cell
PNR	Pre-normative Research
PoC	Proof of Concept
PRD	Programme Review Day
R&D	Research and Development
RCS	Regulations, Codes and Standards
SO	Solid Oxide
SOE	Solid Oxide Electrolyser
SOFC	Solid Oxide Fuel Cell
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle

List of figures

List of tables

Annexes

Annex 1. List of Keywords

This Annex contains the list of keywords used to occupy levels 1.1-.4 of the database. Those keywords shown in grey text are general keywords used when specific details were not provided.

Level 1.1 - Pillar
Transport
Energy
Cross-cutting
Over-arching

Level 1.2 - FCH
Fuel Cells
Hydrogen
Hydrogen and Fuel Cells

Level 2.1 - FC Appl
Transport
Stationary
Portable

Level 2.1.1 - FC Application
Automotive
Aviation
Bus
Car
Marine
MHV
Truck
Train
UAV
APU
CHP
Micro-CHP
Commercial-size CHP
Industrial-size CHP
Small Power
Back-up
Off-grid
Grid-balancing
Portable

Level 2.2 FC Technology
AFC
DMFC
MCFC
PCFC
PEMFC
SOFC

Level 2.3 H2 Application
Production
Distribution
Storage
Purity
Safety
Territory

Level 2.4 H_2 Technology
Electrolyser
Electrolyser-Alkaline
Electrolyser-PCE
Electrolyser-PEM
Electrolyser-SOE
H_2 from Biomass
Methanol Reformer
Multi-fuel Reformer
Bioethanol Reformer
Methane Reformer
Reformer
Solar-photoelectrochemical
Solar-thermochemical
Transportation
Infrastructure
Refueling Infrastructure
Dispensing
Ammonia
Compressed Hydrogen
Electrochemical Hydrogen Compression
Low Pressure Hydrogen Storage
Liquid Hydrogen
Liquid Organic Hydrogen Carrier (LOHC)
Solid-state Hydrides
Underground Storage
Electrochemical Separation
Membrane Separation
Sensors
Metering

Source: JRC, 2019, based on public information from FCH JU.

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

- at the following standard number: +32 22999696, or

- by electronic mail via: https://europa.eu/european-union/contact_en

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from EU Bookshop at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

KJ-NA-30187-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub

ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office of the European Union

doi:10.2760/527632

ISBN 978-92-76-17296-3